

BIM from Concept Design to Fabrication: A Customised Methodology for Façade Consultancies

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Abstract

When an architect ideates a complex building envelope, they often rely on a façade consultancy to develop the final detailed solution of their design. The purpose of this paper is to describe a customised BIM methodology to develop complex building envelopes, evaluating the process followed to convert an architectural concept design to a fabrication reality.

Over recent years, building information modelling has developed greatly in terms of architectural, structural and MEP disciplines. It conveniently advances and analyse the variables of a concept design, and furthermore, coordinates disciplines during the detailed design phases. However, when a technical approach to the envelope's design must be implemented, we need detailed engineering tools to simulate the environmental data, and to analyse and develop the system's fabrication features and assemblies, which are tedious to incorporate on BIM basis.

This paper describes the process followed to develop and execute a building envelope project, starting with a concept design and incorporating virtual simulation processes for the solution to meet its structural and thermal requirements. The final aim is to have detailed drawings and documents of the envelope's elements, with coordinated information for construction and fabrication purposes.

Keywords

Building Information Modelling (BIM), Prototyping, Digital manufacturing

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1 INTRODUCTION

The architecture, engineering, and construction industry (AEC) is facing an era in which technology is improving the way we develop projects, as well as the techniques and the materials used for those projects. Blanco, Mullin, Pandya, and Sridhar (2017), from the McKinsey Institute, explain how new applications and tools are changing the way companies design, plan, and execute construction projects. Since such designs are becoming increasingly complex and expensive, managers must take into consideration solutions for cost improvements, the timelines of projects, and the overall efficiency of the construction process.

The construction industry is one of the largest in the world economy, despite having the dubious honour of being at the tail-end of labour productivity in most countries. Fig.1 shows how the construction sector labour-productivity growth averaged 1% per year over the past two decades, compared with 2.8% for the total world economy, and 3.6% for manufacturing. The complete study is found in the McKinsey report (Barbosa et al., 2017).

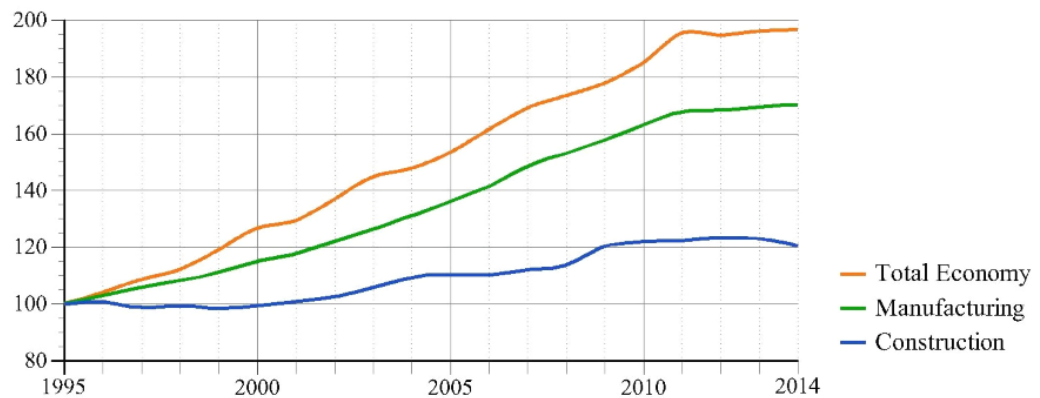


FIG. 1 Global productivity growth trends. Source: McKinsey Global Institute

The McKinsey report outlines how productivity can be improved in the sector and suggests seven actions that the construction industry should adopt: (1) reshape regulation and increase transparency; (2) rewire the contractual framework; (3) rethink design and engineering processes; (4) improve procurements and supply-chain management; (5) improve on-site execution; (6) infuse digital technologies, new materials and advanced automation; and (7) reskill the workforce.

This report also profiles how productivity in the construction sector will increase if some parts of the industry move to a manufacturing-style production system, such as the projects developed by Barcelona Housing Systems or the Osirys Research Project: Forest Based Composites for Façades and Interior Partitions to Improve Indoor Air Quality in New Builds and Restorations.

The AEC industry needs to adopt an integrated advanced platform that spans project-planning, design, construction, operations, and maintenance. Companies can start by making 3D building information modelling (BIM) universal within the company's workflows along with digital collaboration platforms to establish transparency in the design, costing, and progress visualisation of a project. Frontrunners in the construction industry are embracing the BIM methodology, as they

have with other new technologies such as 3D printing, cloud computing and Big Data. The need for synchronised information throughout the project life cycle is beneficial not only for project owners and for contractors, but for the efficiency of every design team involved in the construction sector. In addition, the advanced analytics enabled by the Internet of Things improves on-site monitoring of materials, labour, and equipment productivity.

When the BIM methodology is adopted correctly, it facilitates an integrated design and construction process, and enables an improved on-site execution. This is verified in the McKinsey report by means of case studies that have been developed in different countries around the world, where the use of new technologies, along with Building Information Modelling, allows them to achieve greater productivity.

2 BUILDING INFORMATION MODELLING OF ARCHITECTURAL ENVELOPES

Building Information Modelling (BIM) is a very broad term that describes the process of creating and managing information about a built asset through one or more virtual models that are digitally constructed. BIM technology supports design through its phases, allowing better analysis and control than with manual processes. When completed, these computer-generated models contain precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realised.

In 2014, the European Union urged member countries to adopt BIM on public projects to improve the productivity of the AEC industry. The efficiency outcomes are realised in viewing the design, construction, and operation as a whole: the life cycle of the asset. Traditional construction relies on 2D drawings for information sharing, while BIM provides an added dimension to design, communication, and strategic planning. 3D digital models allow clients and project teams to view a design with more accuracy than any flat image can provide. In 2017, the British Standards Institution published the new ISO 19650, describing the international standards that must be followed for information management using BIM. This standard gives recommendations for a structured framework to manage, exchange, and organise information through the whole life cycle of a built asset, and guidance for organisations to develop the right commercial and collaborative environment so that information is produced in an effective and efficient manner during the project's delivery phases, reducing wasteful activities.

All of these standards are also applicable for the envelope models, where information exchange amongst the architectural and structural teams is crucial. The correct organisation of the information required to develop the project within the team is also a key factor. The following points outline the basis of the BIM methodology and provide specific guidance for the development of the envelope information models.

2.1 DIMENSIONS WITHIN THE DIGITAL MODELS

Everybody familiar with the BIM methodology knows about the dimensions of the models, which comprise the basic difference - as well as the benefit - of using this technology. Building elements have geometrical and classification standards as basic information, which lead to automated



FIG. 2 The new dimensions of BIM models. (Image by Gammon Construction Ltd, 2015)

measurements and billing of the components in the model. We can also associate timeline information to the elements that compose the envelope for planning construction, procurement, and logistics. The sixth dimension of the virtual models is particularly relevant for building envelopes because the solar and thermal simulations will determine a sustainable solution for the performance of the building. Finally, strategic decisions regarding the maintenance and operation of the asset can be made prior to the construction, making the project 7D. This is important in technological envelopes, where the building maintenance unit (BMU) is often needed in the project, and therefore the consideration of the maintenance of the glass elements of the façade is essential in the design phase. By using BIM to develop design options during a project, we can see in a matter of hours the consequences that will result from decisions made in all dimensions of the project.

We can see in Fig.2 how new dimensions are being introduced in the construction scheme to integrate new fabrication methods, such as the use of robots in the process of assembling façade components, or the introduction of the IoT (Internet of Things) in the entire construction process. What is referred to here as BIM 8D is especially interesting in terms of the optimisation of the design process of the envelope, having an automated analysis and a calculation of the façade's external condition, and integrating the standards with which the envelope needs to comply in the same process will provide us with a satisfying design basis.

2.2 COORDINATION WITH OTHER DESIGN DISCIPLINES. INFORMATION EXCHANGE.

The building envelope is currently considered as an independent design discipline in the construction schema, and this is a new departure, since it was always part of the architectural model. This is undeniable when we consider the definition of the discipline provided by the American Nation Institute of Building Sciences: "each design discipline has a different set of skills, professional standards and issues that drive how they operate in the building process".

The building envelope must be fully coordinated with the structural engineers' information, but also with architectural finishes, HVAC, plumbing, and electrical systems. An integrated design of a building requires the various stakeholders and disciplines to interact as early as possible in the process, and making available the clear information that is required at each stage of the project for the resolution of design objectives.

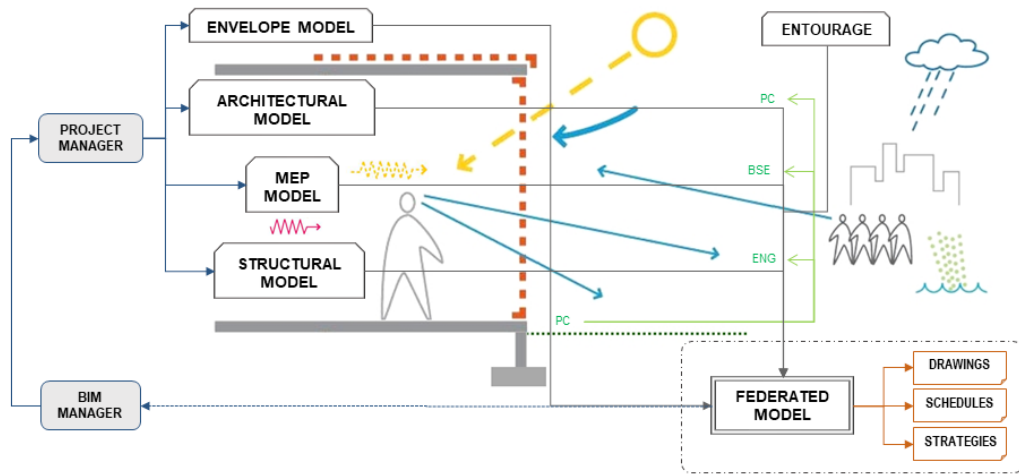


FIG. 3 Diagram of a BIM design collaboration team.

“A building envelope must reconcile many requirements –ventilation, solar heat gain, glare control, daylight levels, thermal insulation, water management, materials, assembly, sound and pollution control– making the design a complicated balancing act.” (Lovel, 2013).

The integration of environmental systems in the solution of the envelope must be a synthesised and integral part of the design process. For this to be accomplished there must be a comprehensive and clear information exchange between all the disciplines involved in the design of the asset, which is achieved more easily using BIM models.

DESIGN DISCIPLINE	REQUIRED INFORMATION	INFORMATION DELIVERED
ARCHITECTURE	Geometry, materials, aesthetics	Surface perimeter lines
	Space characteristics, occupancy	Accesses, comfort quality
STRUCTURE	Supporting elements	Façade system loads
	Characteristics, resistance	Anchorage & stiffeners
MEP SYSTEMS	Ventilation, heating and cooling	Thermal gains
	Drainage strategy, electric support	Façade transmittance

TABLE 1 Basic information exchange for envelope's development.

2.3 MANUFACTURED OBJECTS FOR BIM

Many platforms facilitate façade components for virtual models, where thousands of objects and construction systems can be downloaded with all the accompanying information to cover all the levels of development (LOD) needed in the project. This data is useful when the aim is to create an as-built model for operations and we need to incorporate all the characteristics of the building components for their future replacement or maintenance (LOD 400). However, all this information is unnecessary in the project phase, when we need to define the solution clearly in order to develop shop drawings.



FIG. 4 Level of development of a curtain wall system. (Image by BIM forum)

The problem that many designers face when downloading these elements is the size of the files, due to all the associated information and the custom variables that the elements present. As façade consultants, we often work with customised solutions or non-commercial building components made for a specific project, and therefore, we must create new specific components for each project. Following the project progress timeline, which can be associated with the different LOD of the building components, we start by defining the 3D geometry and introduce the information and details needed to define the element. The detailed development of these bespoke assemblies is one of the frameworks of this optimisation.

Part of the engineering proposals given by the façade company is the provision of an extremely detailed solution, which is in contrast with a typical architecture detail. Experience has taught us that we cannot associate every detail of the building elements in order for them to appear when making a section or a plan view of the model. Maintaining the same level of detail of components on a BIM model as if it were a CAD drawing will simply cause the model to crash. The aim of the 3D model is to coordinate the façade solution with other disciplines and share information with them. Most of these 2D details are unnecessary for this purpose, but are required for drawings produced for fabrication purposes and for detailed specifications. Being able to discern what information is necessary for the specific purpose in each phase of the project is the first step of the optimisation process.

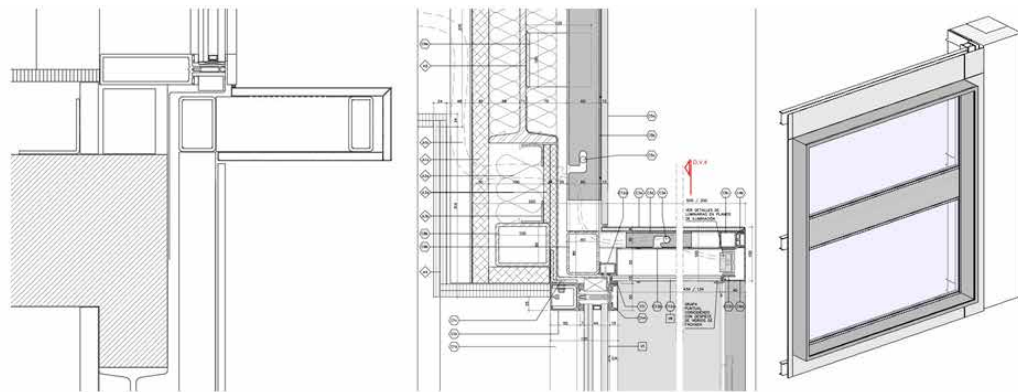


FIG. 5 A detailed envelope drawing versus the BIM model.

2.4 FRAGMENTED DELIVERY PROCESS VERSUS INTEGRATED STRATEGIES

One reason for the industry's poor productivity record is that it still relies mainly on paper to manage its processes and deliverables such as blueprints, design drawings, procurement and supply-chain orders, equipment logs, daily progress reports, and punch lists. Due to the lack of digitisation, information sharing is delayed and may not be universal.

Fig. 6 represents the different design approaches taken by the consultancy when delivering a project. The first diagram represents the traditional workflow and technical roles, while the second shows an integrated BIM methodology with the software simulations tools within the project.

Most of the BIM protocols focus on collaboration techniques and the various disciplines involved in a project, as well as the information exchange between them, which is key to developing a comprehensive and well-coordinated project. These fundamentals are also applicable to the work developed by the team of consultants when creating and executing a building project. It is necessary to move over to integrated strategies and collaboration platforms for sharing information within the companies to increase productivity, and avoid the loss of information and lack of coordination. Incorporating BIM into the design workflow of the envelope project allows us to evaluate it as a whole and comprises a unique database for all the information associated with the components of the building. The benefits of BIM for subcontractors and fabricators are widely analysed in the BIM handbook (Eastman, Teicholz, & Sacks, 2011).

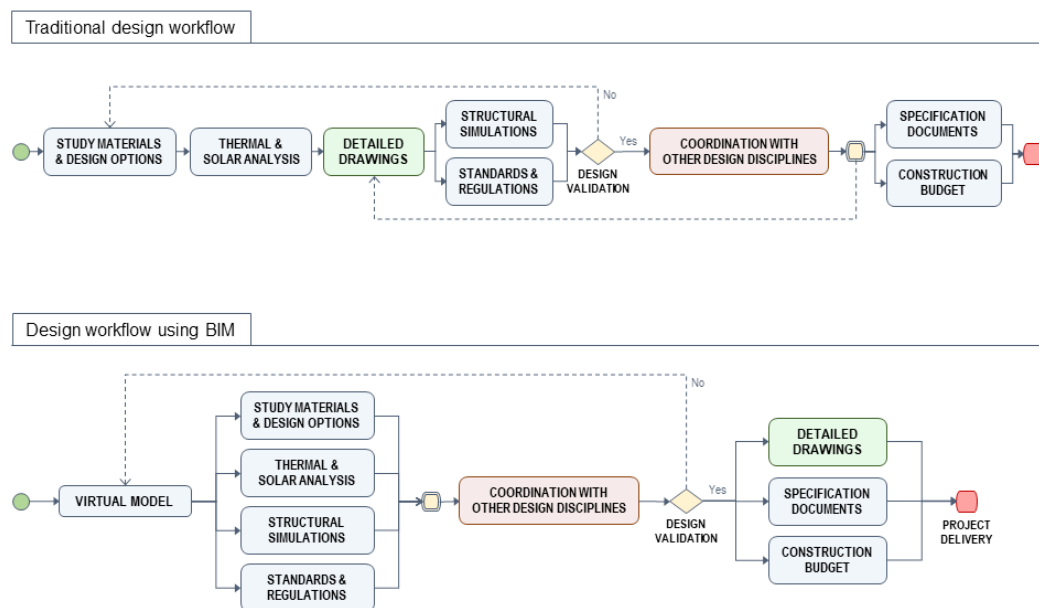


FIG. 6 Traditional design workflow versus a BIM integrated workflow.

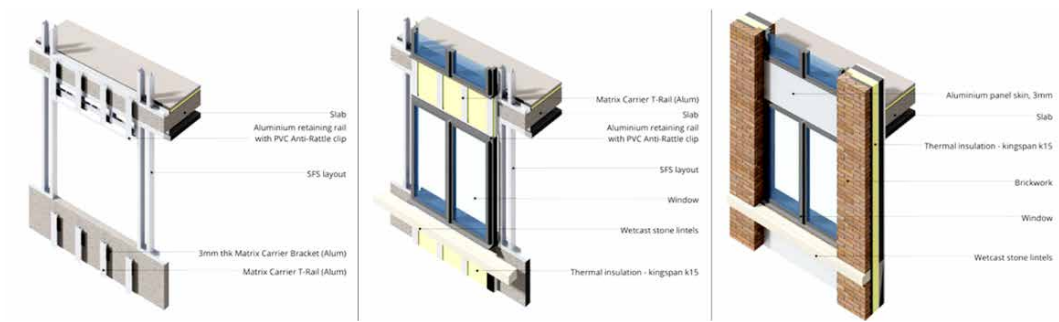


FIG. 7 Detailed fabrication model. (Image by F+A+T Facades, U.K)

3 OPTIMISATION OF THE DETAILED DESIGN METHODOLOGY

As a consultancy, we must adapt our workflow to the criteria established by our clients, and each one has a different way of handling the information they give to the design disciplines involved in the construction project. We work with the BIM software Revit, from Autodesk®, but our clients may not work with the same platform or even with BIM at all. Therefore, the first step for our design team is to translate the basic architectural and structural information received -when they are not Revit models - in order to define a common starting point from which to develop the project and follow the same BIM methodology regardless of what the incoming source is. We also have to define an exchange procedure to coordinate the design process, and this depends on the software used by our clients.

The type of building determines the objectives and the main characteristics that need to be obeyed by the envelope. We develop a wide variety of projects, such as offices, hotels, greater complexes such as shopping malls or refurbishment of existing buildings. Whatever the type of building, it is important to establish how our team will use the model, as well as determining the uses our client needs for the efficiency of the design process.

In multiple phases of a building project, the envelope designers need to interact with various simulation tools to predict the performance of the model, which makes interoperability among different programs a necessity (Chi, Wang, & Jiao, 2015). We use mainly Autodesk® tools, which implies that they have a priori good interoperability between each other, although this is not always directly achieved. For example, within the Autodesk® tools, there is a gap between the software used in architecture and software intended for fabrication: architecture, engineering, and construction (AEC) is a different collection than the one intended for product design & manufacturing (PDM).

Every façade solution is preceded by the geometry and the materials ideated by the architect. The design of the building envelope takes into consideration the form, size, and type of the glazing elements in order to create an energy efficient model with a maximum level of acceptable daylight. The BIM-based performance optimisation described in the BPOpt article (Asl, Zarrinmehr, Bergin, & Yan, 2015) can be used to evaluate the variables and search for an optimal solution at an early stage of the design, which is frequently done prior to the detailed development of the project that supports the architect in the design of the façade.

The consultancy has to find the best technical solution to satisfy the design intent of the architect, while also considering the structural stability of the façade, the thermal conditions required in the building, and the compliance of international construction standards without disregarding the aesthetic of the envelope.

TASK DEVELOPED	INPUT	PROCESS - SOFTWARE	OUTPUT
Architectural and structural base for the façade design	2D .dwg Files 3D .sat Models	AutoCAD Dynamo	Coordination model
Envelope geometry	Coordination model	Revit	Base model
Basic solar analysis	Façade base model	Revit sun path / Insight	Design criteria
Structural constructability	Façade base model	Dynamo / Excell	Structural criteria
Detailed development	Detailed drawings	Inventor / Revit	Fabrication module
Detailed sun analysis	Geometry model	Dynamo / Ecotect	Performance
Detailed structural solution	Façade model	Revit / Dynamo / Robot	Structure model
Execution project	Envelope models	Revit / Dynamo / Inventor / AutoCAD	Drawing production

TABLE 2 Software integration and automation processes considered.

We usually start the detailed project from 2D CAD drawings or 3D rhino files received from our clients, where the geometry of the building is defined and the structure outlined. Using the BIM platform along with its open source visual programming tool Dynamo allows this process to be automated and have a reliable construction model with which to start the process of detailed design of the envelope. BIM represents the building as an integrated database of coordinated information, and enables sharing this data for interoperability between prevalent software tools for specific simulations.

Once we start to develop the solution, we have to analyse the characteristics of the structure, and the geometry of the project as a whole, to consider an optimal technical solution. The size and form of the building elements have already been defined on a 3D coordination basic model. Performing a basic analysis of the solar path and the radiation reaching the façade within the BIM model will establish the design criteria we need to consider. Having an initial estimation of the wind loads and the stability of the structural components is also necessary at this stage to have reliable dimensions of the components that will be assembled in the solution. This process can be optimised using Dynamo to extract the geometrical information needed from the model and automatically introduce it into calculation sheets.

Once these analyses have been completed we have the technical criteria to do a first sketch of the typical detailed solution of the façade that needs to be validated by the architect in order to establish the coordination dimensions with the structure and the rest of the disciplines.

We can then start to develop the detailed envelope model with the typical solutions considered. Using BIM coordinated models with other disciplines allows us to detect and analyse different encounters that need to be solved on the project being executed. Performing clash detection with structure, interior finishes, and MEP systems is a key process for automating this task.

When the structural elements of the façade are complex, we introduce specific analysis tools like Autodesk Robot® to our workflow. Finally, when the assemblies of the components are especially challenging we also use fabrication software to develop a detailed 3D model of a façade module. Autodesk Inventor® allows us to assemble the components of a module and have a detailed analysis of the element's structural performance. This software will also allow us to generate drawings showing the assembly instructions of the components on a timeline basis.

Whichever software is used throughout the envelope's development, the final goal of the detailing process is to have all the documents needed for the construction of the building. The implementation plans and technical documentation of the systems must be clear, coordinated, and comprehensive.

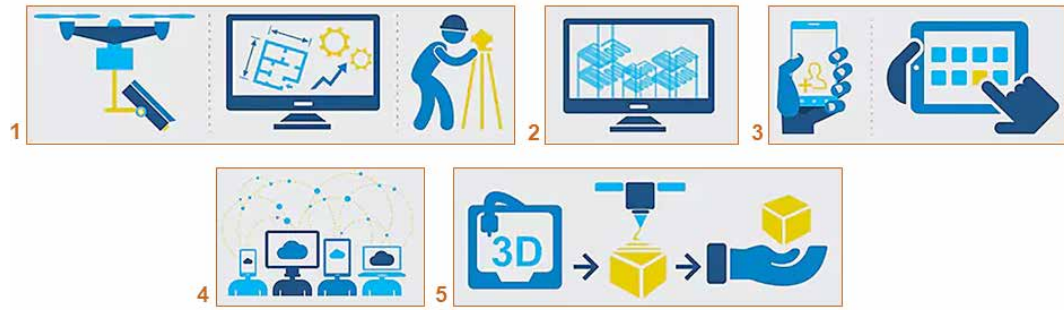


FIG. 8 Digital construction organization. Source: McKinsey Global Institute

4 EVALUATION OF THE PROCESS

The knowledge generated with each project that we develop in the consultancy with the BIM methodology differs, in part because we never work on the same building types or with the same materials, and partially because our workflow must be adaptable to the one our clients follow.

Fig. 8 illustrates the five trends that will shape the digital construction organisation of the near future, developing the next generation of digital-native leaders to deliver projects of the future: (1) higher definition surveying and geolocation, with rapid digital mapping and estimating; (2) next-generation of 5D building information modelling; (3) digital collaboration and mobility, moving to paperless projects; (4) the Internet of Things and advanced analytics, that will enable intelligent asset management and decision-making; and (5) future-proof design and construction, by integrating materials and methods of the future into our designs.

Every project becomes an opportunity to test and refine our workflow, optimise the interoperability and coordination processes within our team and discover new digital solutions that can be tested on future projects. For this to be accomplished, there needs to be not only a commitment to invest on innovation, but also continuous training of team members -as well as the leaders- who need to use the latest equipment and digital tools.

5 CONCLUSIONS

In the Spanish construction system, there are several phases of the design project to undertake before we can obtain the construction permits given by the appropriate authorities, and once these permissions are obtained and the design is finalised, the builders are chosen to materialise the project.

Using Building Information Models allows fewer errors during the on-site construction process. Developing and executing a project solely of the façade does not save time in the construction process. Quite the contrary, we must develop a virtual coordinated construction model of the entire envelope, instead of developing the typical details of the façade components needed for the subsequent fabrication process. Not only should the time spent in developing a façade engineering project increase, but the owner's budget for the design phase should also increase accordingly, since, with the use of BIM, savings are realised in the construction phase and the management of the asset.

The process of digital collaboration and mobility means moving away from paper toward online, real-time sharing of information to ensure transparency and collaboration within a project. For this to be accomplished, there needs to be a change of mentality in many fields within the construction industry, and this goal is, unfortunately, a remote one today.

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